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Site Investigations in Limestone Formation for Pile Foundation Design

Name of Speaker : Ir. Mak Wai Kin

Date : 25th February 2025

Venue : Hotel Armada, Petaling Jaya

SOLSTRUCT Engineers Sdn. Bhd.
Engineering Through Imagination

Content

- What is Site Investigation (SI) work
- Why SI is required
- When SI work shall be conducted
- Who is responsible for SI work
- Where is the SI location
- How to ensure SI data is sufficient

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What is Site Investigation ?

According to MS 2038:2024,

Site Investigation **includes desk studies, field reconnaissance, and field and laboratory work within geographical, geological, hydrogeological and environmental contexts.**

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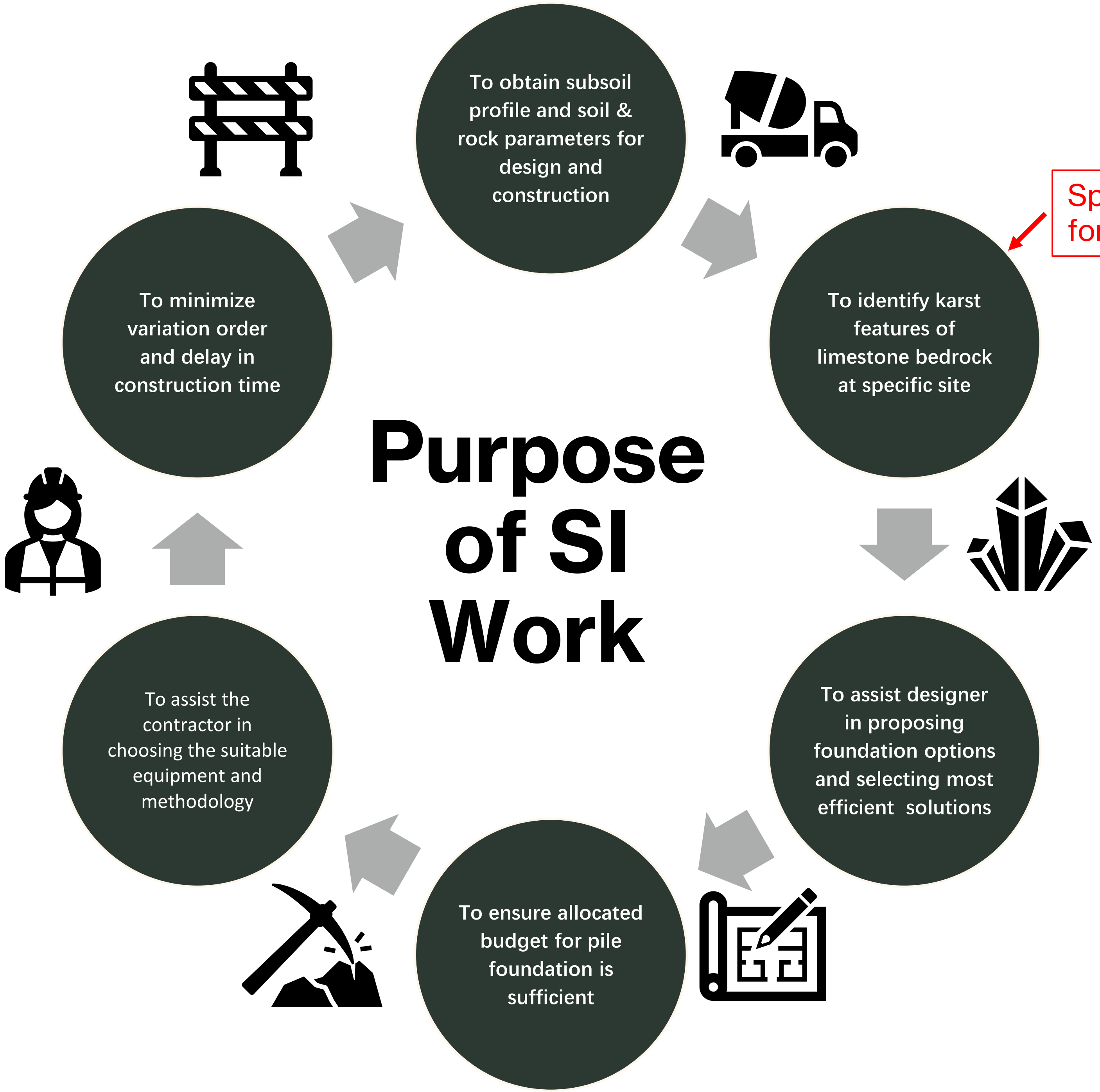


Specifically for limestone formation area

Type of Foundation

Shallow Foundation	Deep Foundation
• Pad Footing • Strip Footing • Raft Foundation	• Steel Pile • Hammer Pile • Jack-In Pile • Micropile • Caisson Pile • Bored Pile • Barrette Pile
Light-loaded structure	**Heavy-loaded structure**
- Low rise building/structure - Competent ground or rock at shallow depth	- building, bridges, viaduct, underground structure - Competent soil layer or rock at deeper depth

Typical Piling Foundation in Limestone

Hammer Driven Pile

Jack-In Pile

Bored Pile

Micropile

Limestone Formation

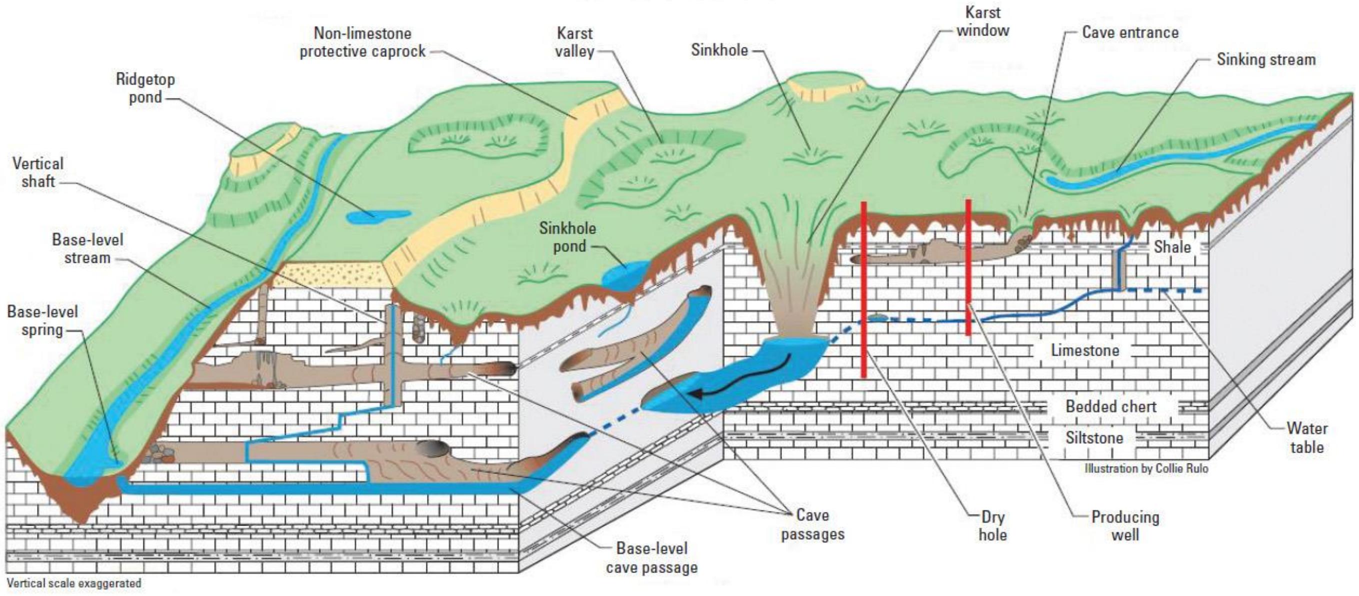
Sedimentary rock primarily composed of calcium carbonate **($CaCO_3$) often derived from marinse organisms or through chemical precipitation.**

Soluble in mildly aqueous environments such as carbonic acid (H_2CO_3).

Majority of limestone underwent karstification, a process which limestone is eroded and shaped by dissolution thus forming karst landscapes such as voids and pinnacles.

Development of Karst Features in Limestone

Undergoes the process of **chemical dissolution** caused by slightly acidic water.



- **Pinnacles**

Water infiltrates through fractures and dissolves softer limestone. **Harder limestone remains, forming sharp and irregular spikes.**

- **Cavities**

Water dissolves limestone along fractures and bedding planes, forming **small hollow spaces and gradually expand. Cavities may be filled or unfilled.**

- **Voids**

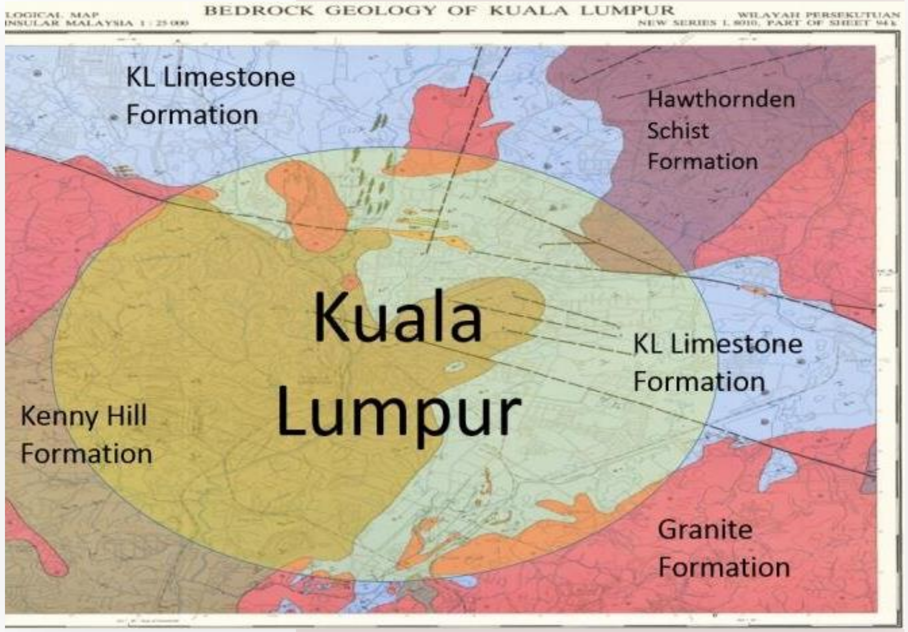
Continuous dissolution of limestone expands cavities into large voids.

- **Floaters**

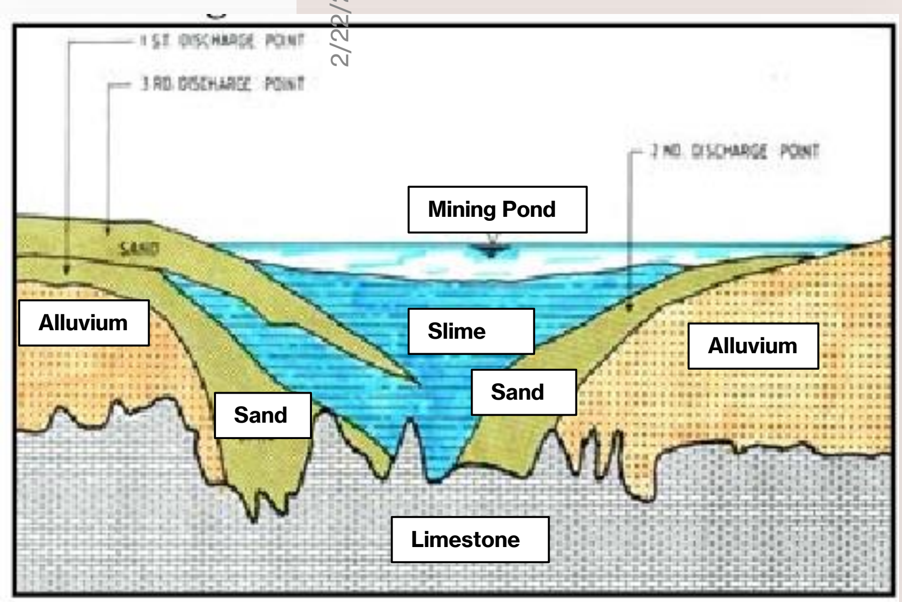
Isolated rock blocks within softer soil due to dissolution process.

- **Cliffs**

Erosion and dissolution undercut limestone layers, creating steep slopes.



Geological Map of Kuala Lumpur



Tin Mining Remnants of Heterogenous Nature (Chan & Hong 1986)

Kuala Lumpur Limestone

- A sedimentary rock (limestone) that was being intruded by the igneous rock (granite).
- Consists of highly erratic karstic features.
- Historically associated with tin mining areas.
- Ex-tin mining areas are covered with remnants of highly heterogeneous nature of slime to sand.
- Mining activities left behind numerous ponds and remnants consist mainly of sand and clay slime which forms overburden materials over the limestone.
- Occurs at shallow depths (less than 25m) except in Kenny Hill formation (encountered until 200m deep).

Piling Issues in Limestone Formation

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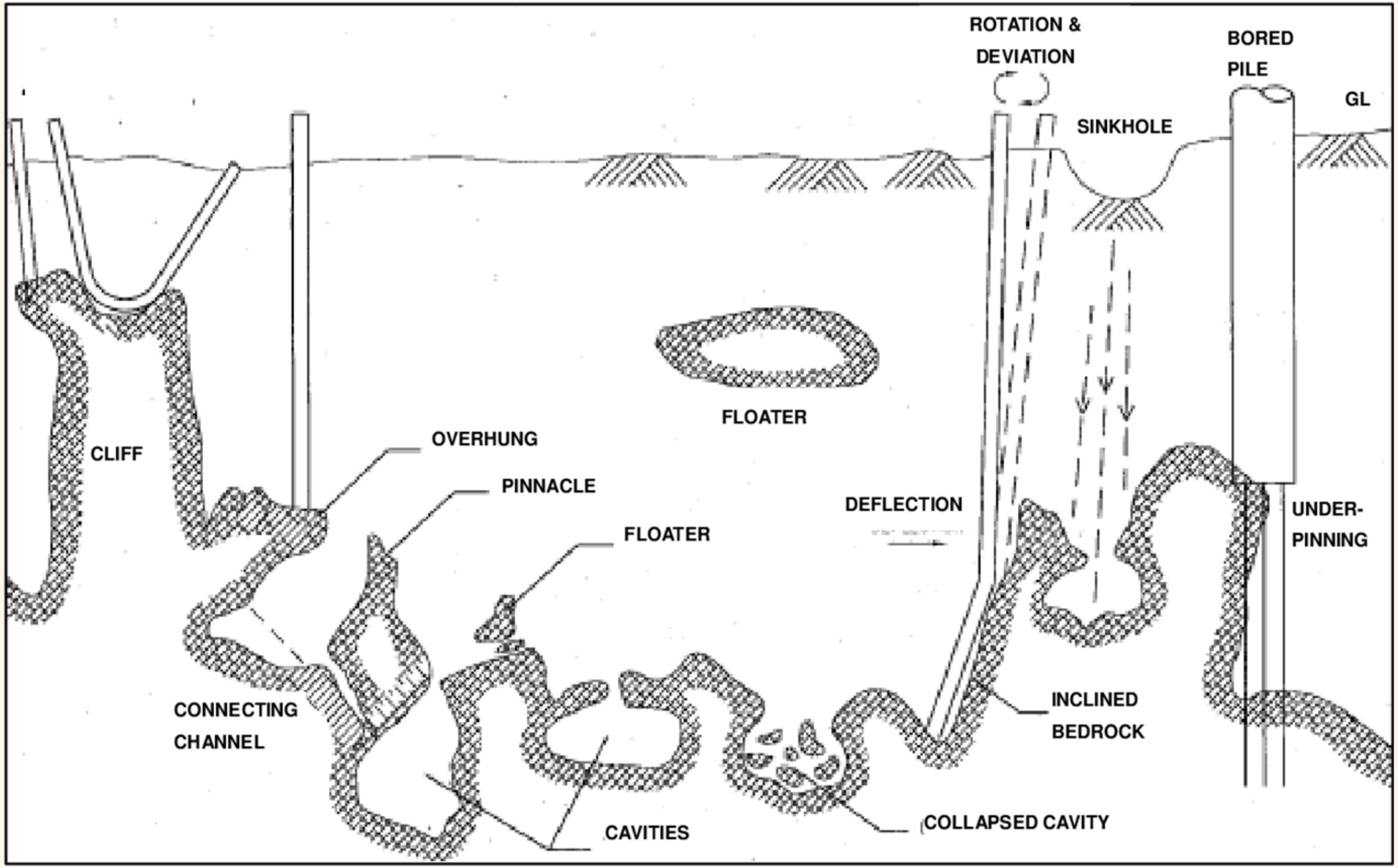
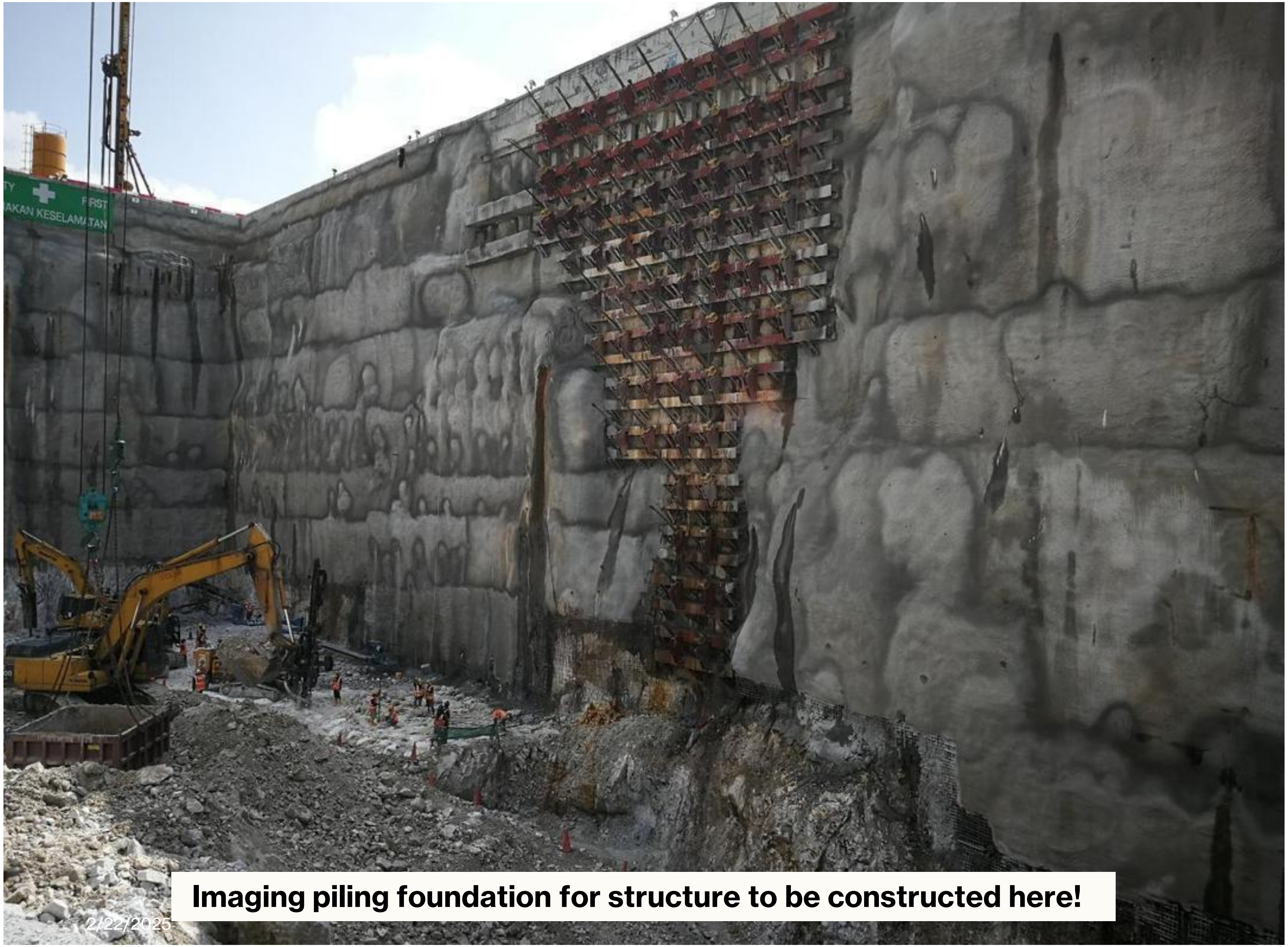
Karst features in limestone areas which causes piling problems (Neoh, 1998)



Sinkhole in limestone formation.



Imaging piling foundation for structure to be constructed here!

Phases of Site Investigation Work

Stage 1	Preliminary
Stage 2	Detailed SI
Stage 3	Construction

- Desk study and field reconnaissance should be conducted first.

Stage 1 : Preliminary

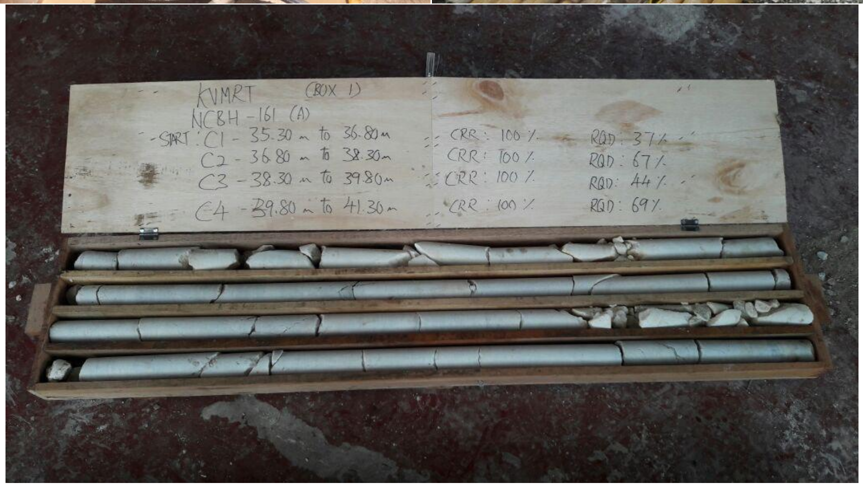
- Conducted prior to the submission for approval of Developer Order (*Kebenaran Merancang*) from Local Planning Authority.
- A few or widely spaced boreholes are proposed to establish general geological condition and identify potential geotechnical risks due sub-surface conditions.
- Initial data from preliminary stage can help to design an effective programme for detailed investigations in later stages and ensuring the project requirements are met.

Stage 2 : Detailed SI

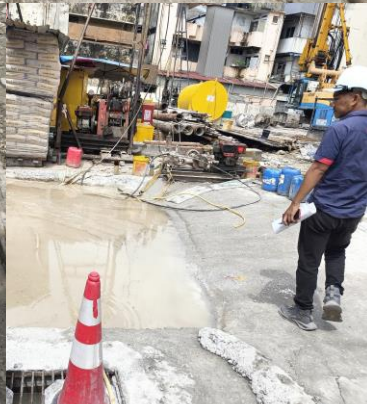
For this stage, adequate site investigation work shall be carried out for detailed design.

Typically, boreholes would be conducted and can be complemented geophysical survey particularly for larger site.

This stage is important for design purpose and project cost estimation.







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Stage 3 : Construction

- Conducting confirmatory boreholes at pile locations with large load demands can help to verify the findings of earlier SI work.
- When bored pile foundation is chosen, rock or cavity probing in limestone rock at each pile cap location is becoming standard practice.
- In areas where highly erratic karstic features are found, additional rock or cavity probing is recommended to further assess the conditions.

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Case Study 1

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Project Information

A building structure to be constructed at Bulatan Kampung Pandan, Kuala Lumpur.

It was to be built over the existing road tunnel.

The original design for the foundation system was bored pile.

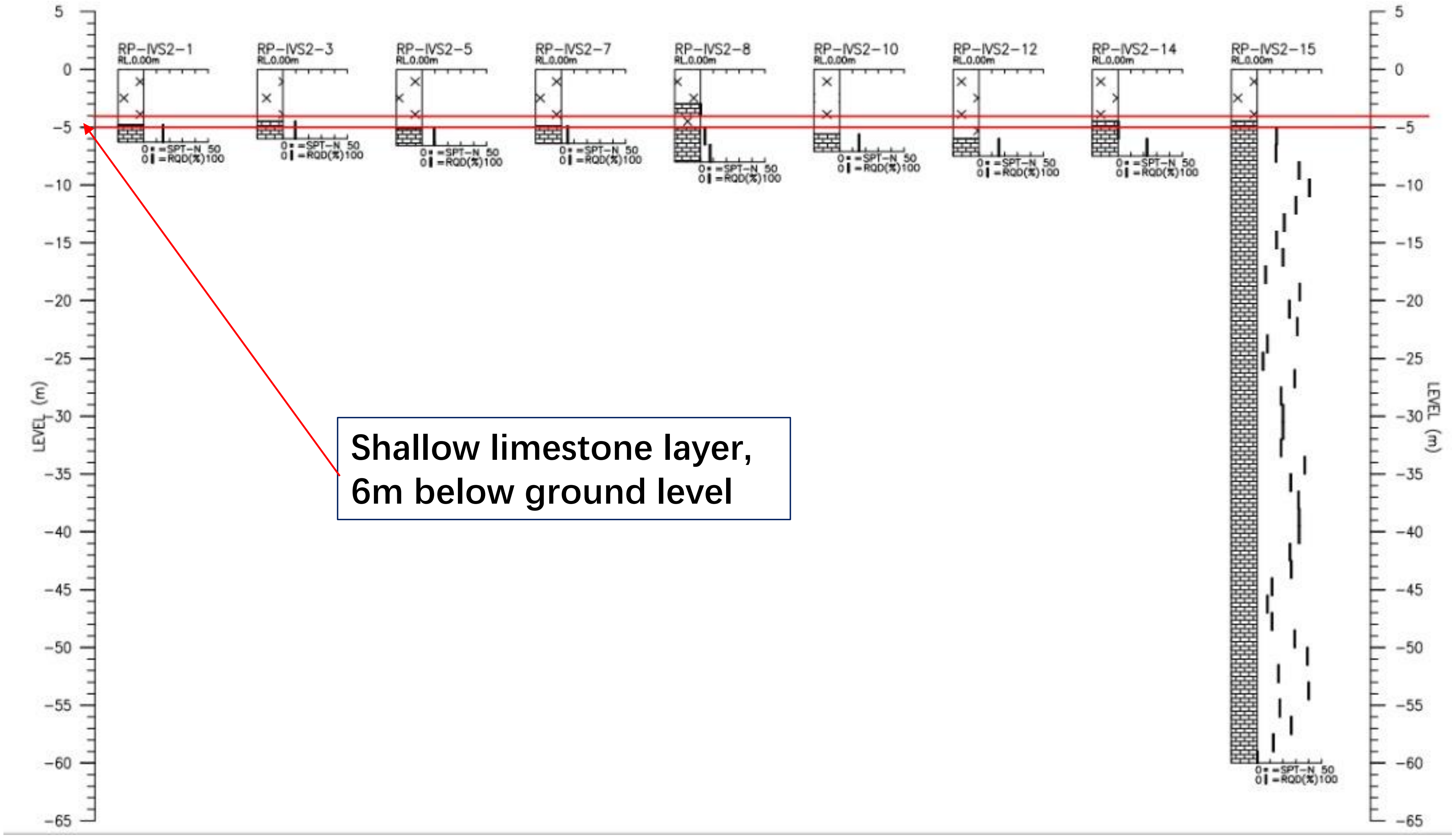
Scope of SI

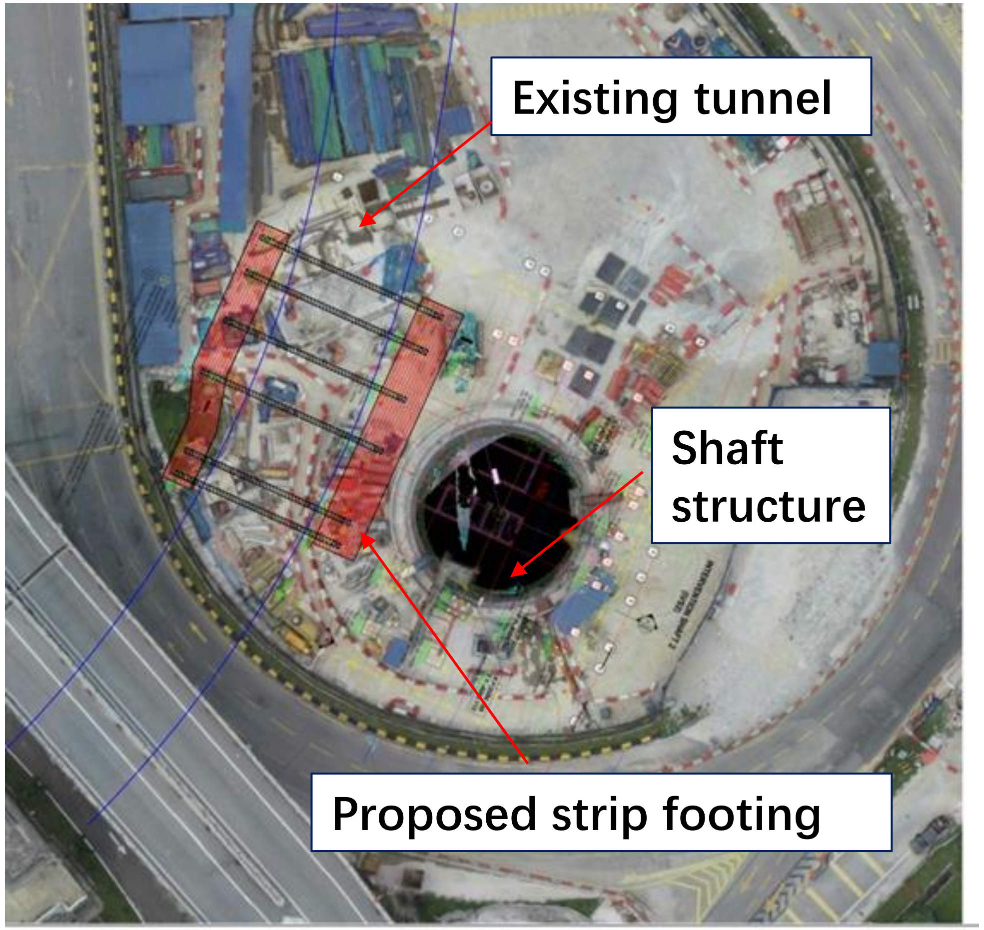
Desk Study
Review existing geological maps, previous investigation reports and historical data of site.

Field Exploration
Standard Penetration Test (SPT) - determine subsoil profile and collect soil and rock samples.
Rock Probing – conducted to verify the limestone bedrock level and its condition.

Laboratory Testing
To determine properties of collected samples at site.

Rock Probing Results





SI Results

Kuala Lumpur Limestone Formation

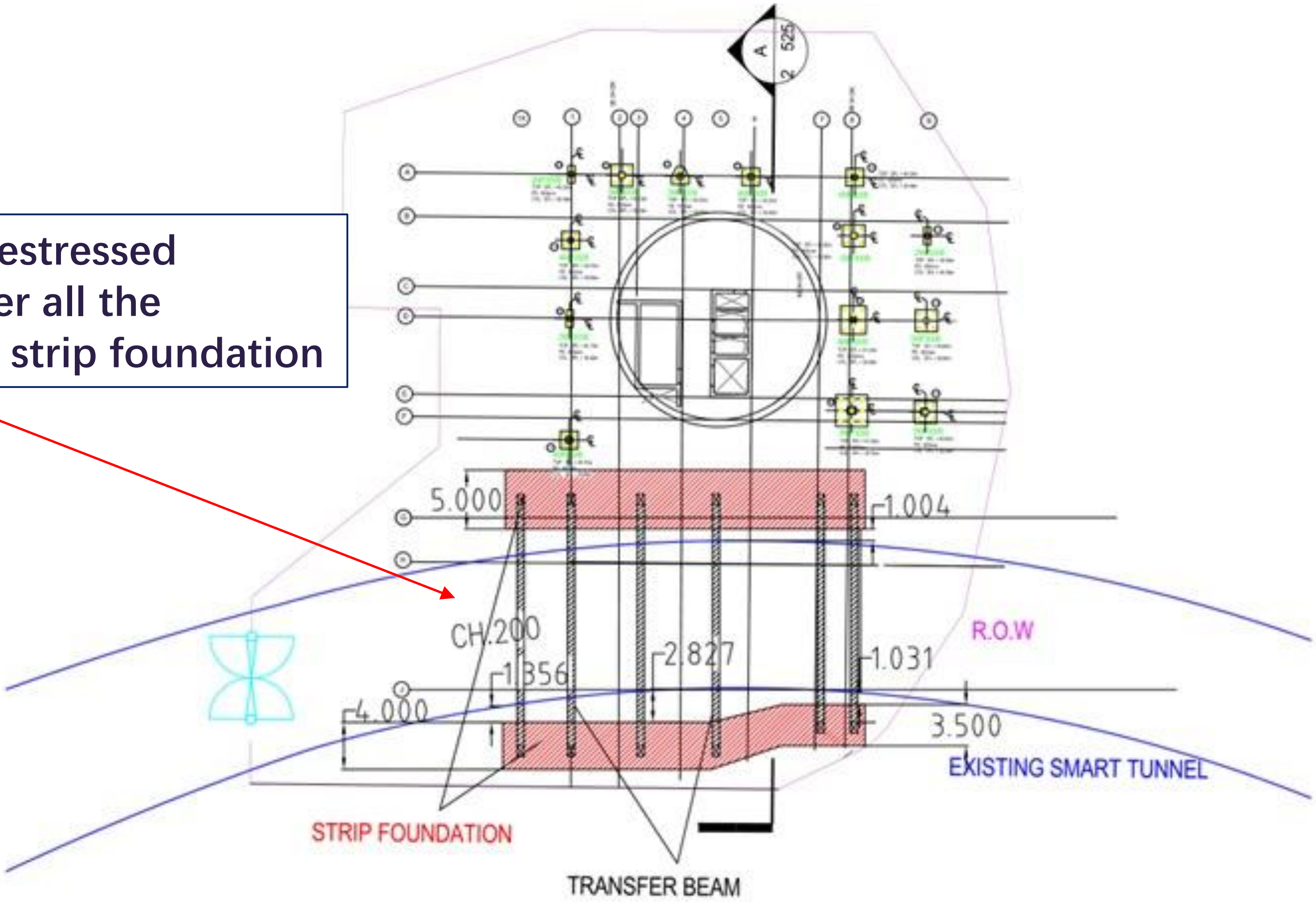
Site is underlain by Kuala Lumpur Limestone with the limestone layer being approximately 6m below ground level.

Strip Footing

The foundation type was changed from bored pile to strip footing after detailed engineering assessment.

Proposed Design of Project

strip foundation and prestressed transfer beam to transfer all the building loads onto the strip foundation



Actual Condition of Site After Excavation

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Abandoned construction structures from the previous construction of SMART tunnel such as RC wall, gabion wall, pipes and even concrete column was found during excavation;

Actual Condition of Site After Excavation

Discussion

- Desk study and field reconnaissance should be conducted at the start of investigation.
- Search for site history to determine earlier use and state of the site is important.
- Always be prepared for uncertainties and considered in foundation design as we have no clear visions what lies underneath.

Case Study 2

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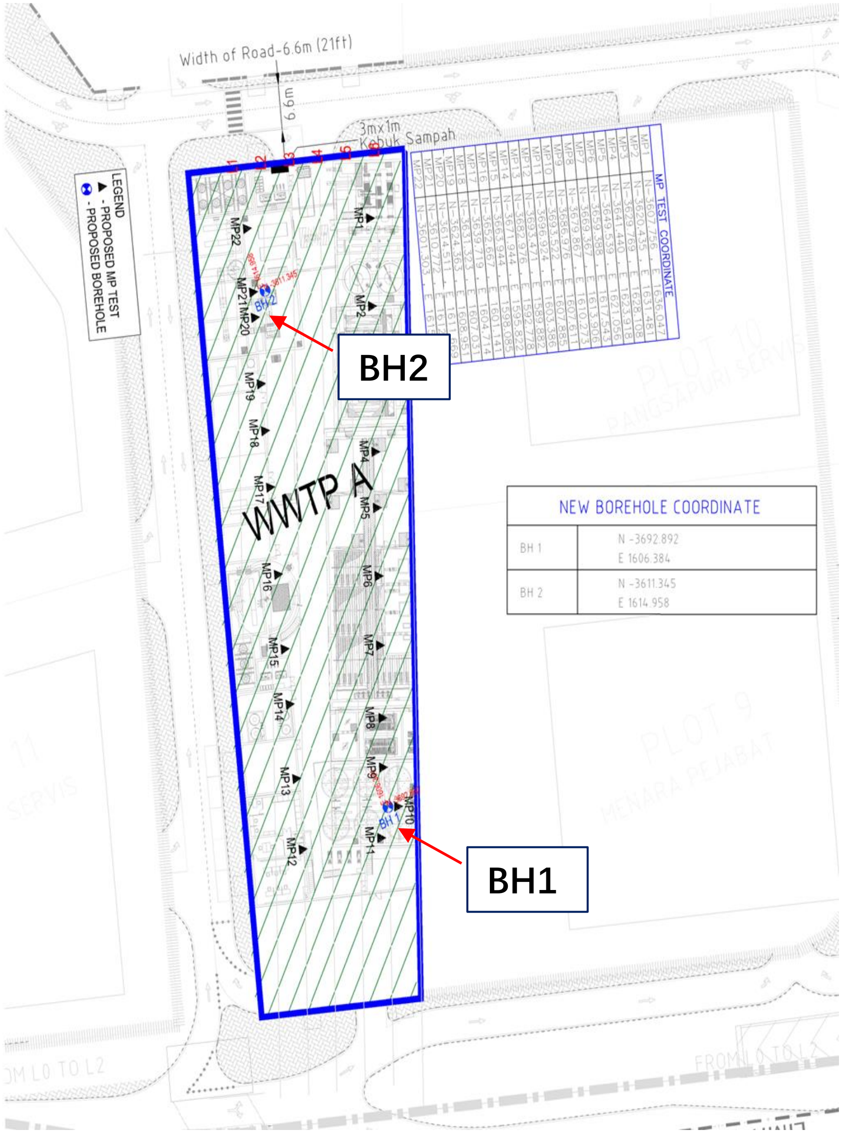

Project Information

A wastewater treatment plant (WWTP) project in Kampung Pandan of about 1.1 acres in land size.

Scope of SI

Desk Study
Review existing geological maps, previous investigation reports and historical data of site

Field Exploration
2 BH and 22 MP were conducted at the proposed site

Laboratory Testing
Moisture content, Atterberg Limit, PSD (for soil samples)
UCS and Point Load Test (for rock samples) tests were conducted based on SI report

Result of Site Investigation (BH1 and BH2)

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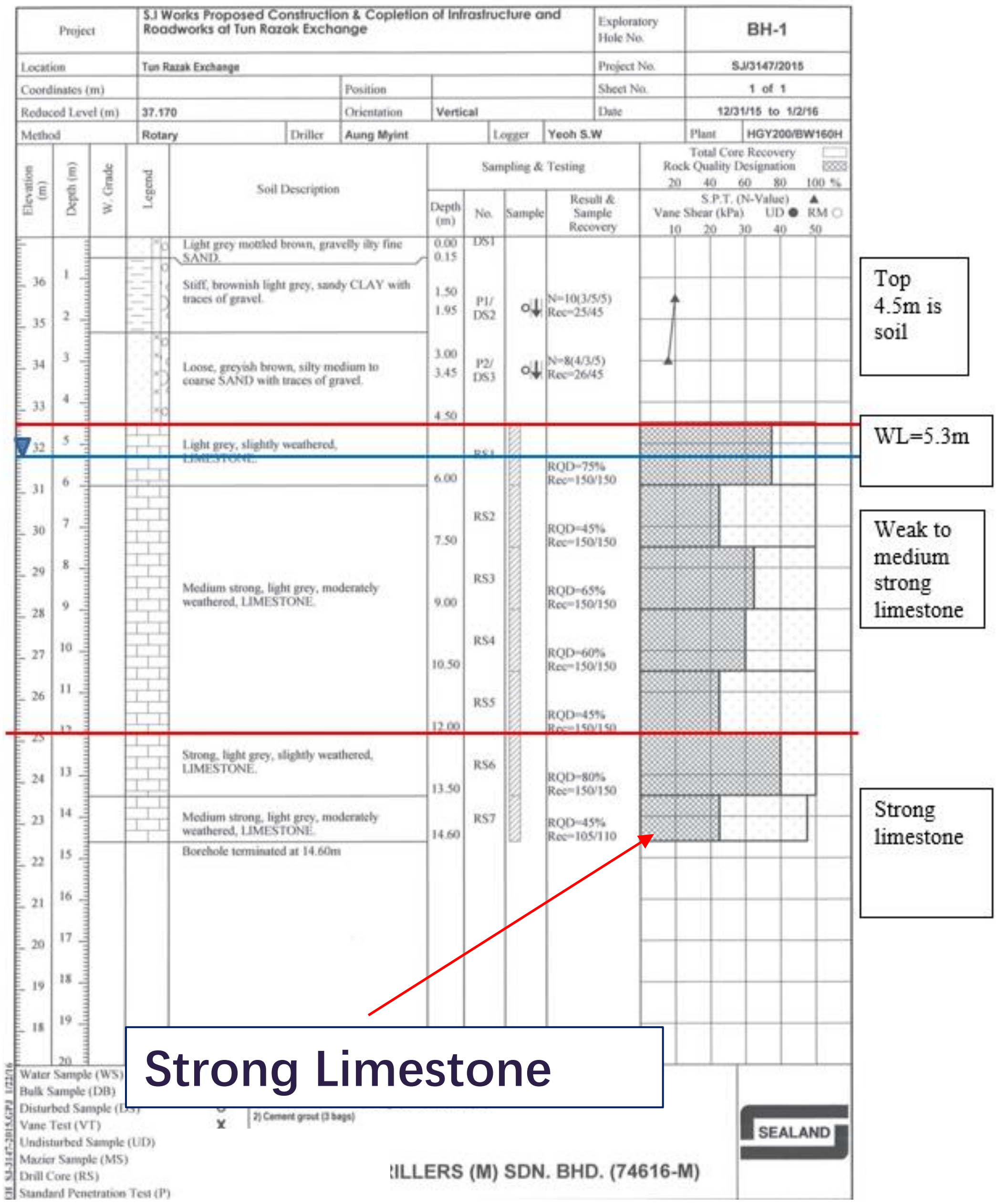
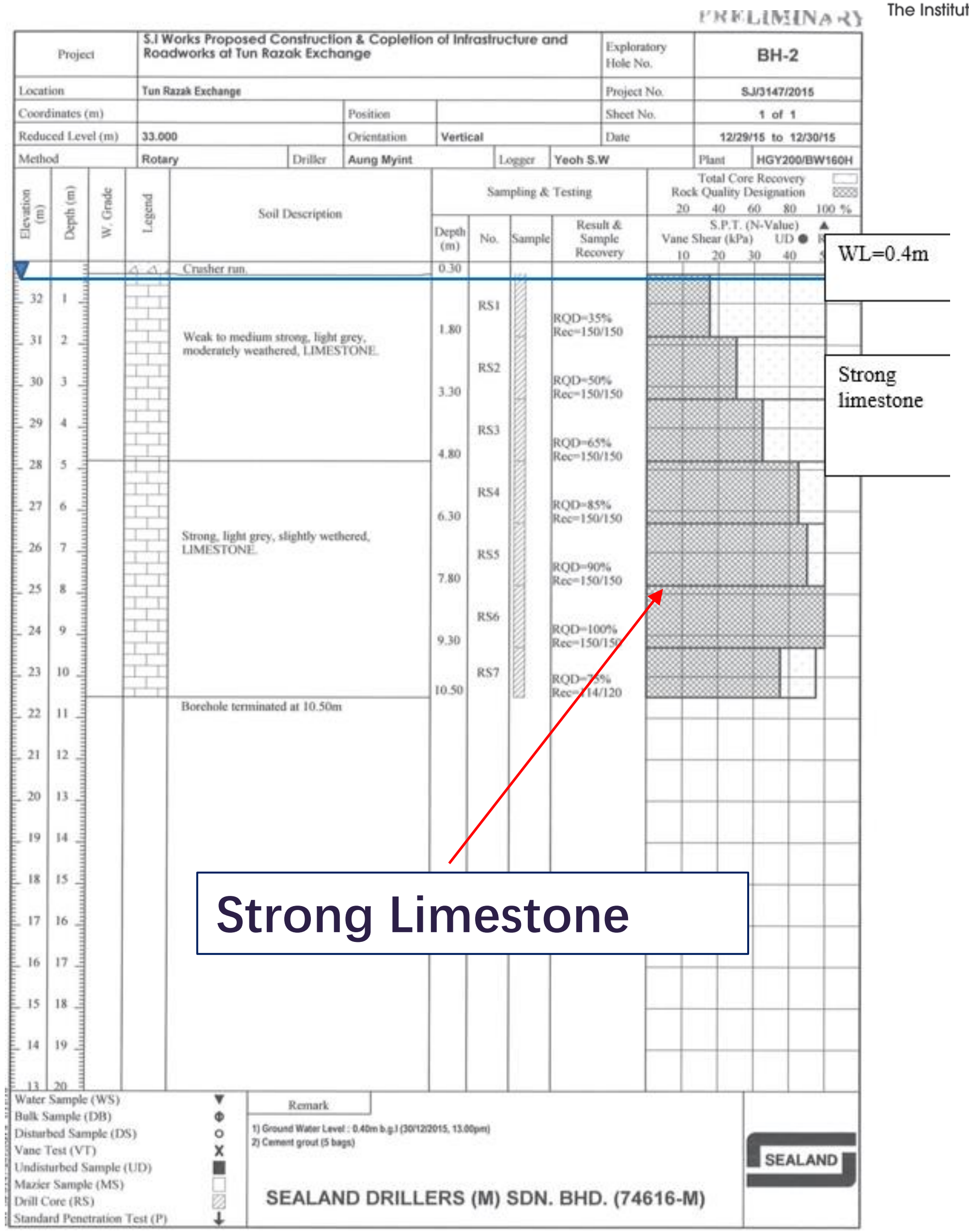
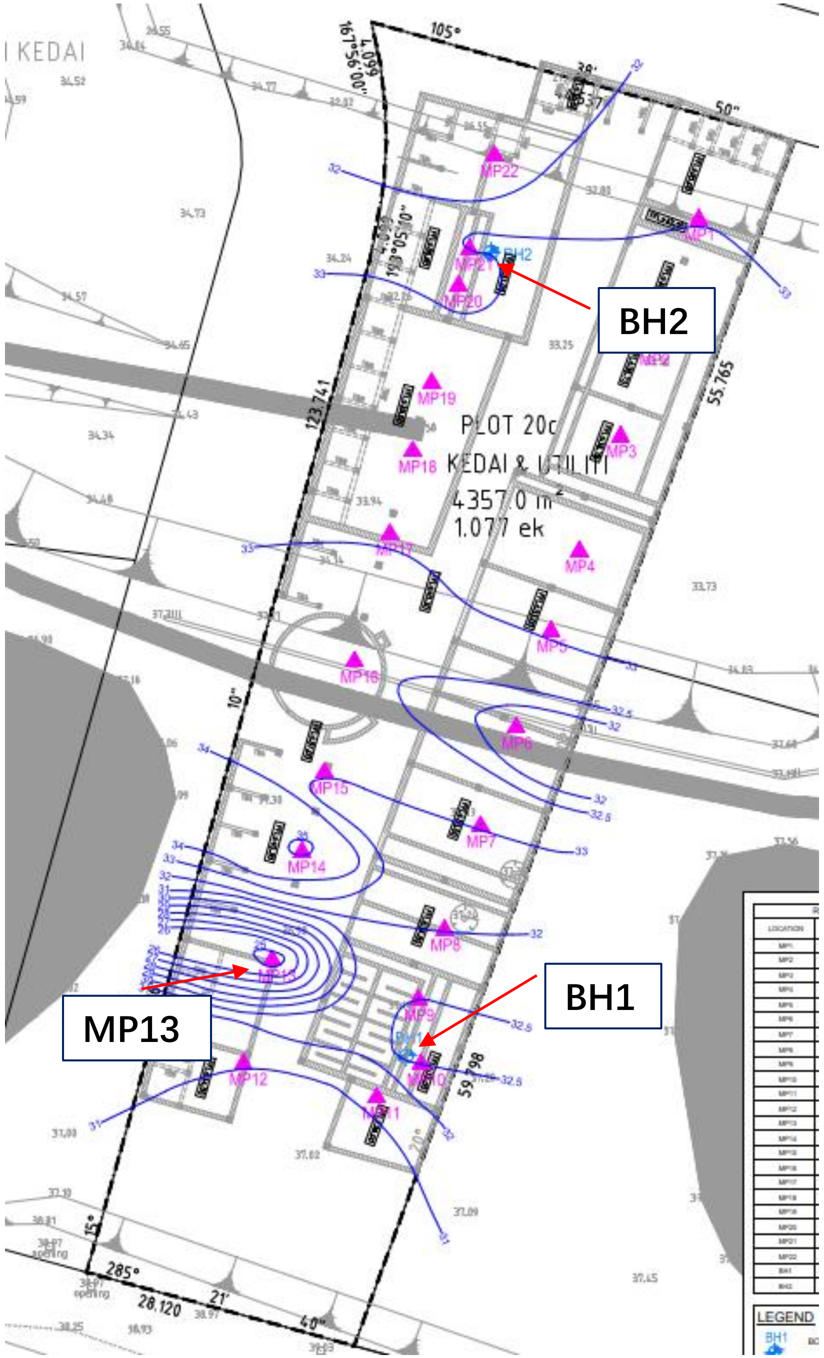




Summary of Rock Head Level

ROCK HEAD LEVEL		
LOCATION	REDUCED LEVEL (RL m)	DEPTH BELOW egl (m)
MP1	33.00	egl
MP2	33.33	egl
MP3	33.45	egl
MP4	33.35	egl
MP5	33.34	egl
MP6	31.451	4.8
MP7	33.10	3.3
MP8	31.98	4.2
MP9	32.59	3.6
MP10	32.50	3.9
MP11	31.85	4.2
MP12	31.64	4.5
MP13	24.50	11.7
MP14	35.10	1.2
MP15	33.10	3.0
MP16	32.613	4.2
MP17	33.40	egl
MP18	33.32	egl
MP19	33.32	egl
MP20	32.45	egl
MP21	33.39	egl
MP22	31.90	egl
BH1	32.67	4.5
BH2	33.00	egl



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SI Results & Findings

Limestone Formation
Site is underlain by Kuala Lumpur Limestone with the limestone bedrock layer approximately 4.5m below ground level (BH1) & 0.3m below ground level (BH2)

Termination Depth
14.60m (BH1) & 10.50m (BH2), rock head level for MP test.

Rock Quality
Bedrock consist of medium to strong limestone (RQD between 35% - 100%)

Proposed Foundation
Foundation design using raft as the bedrock level is shallow.

Actual Condition of Site

- A long and wide solution channel resembling a "stream" was discovered.
- It was detected by only one MP test which was initially considered to be a localised depression in limestone rock.

Discussion

- Probably additional MP test points around the suspected "depressed" area would be able to detect extent of solution channel.
- Important to allocate some budget for additional investigation point during SI work
- Geophysical survey might be useful for site with shallow limestone bedrock.

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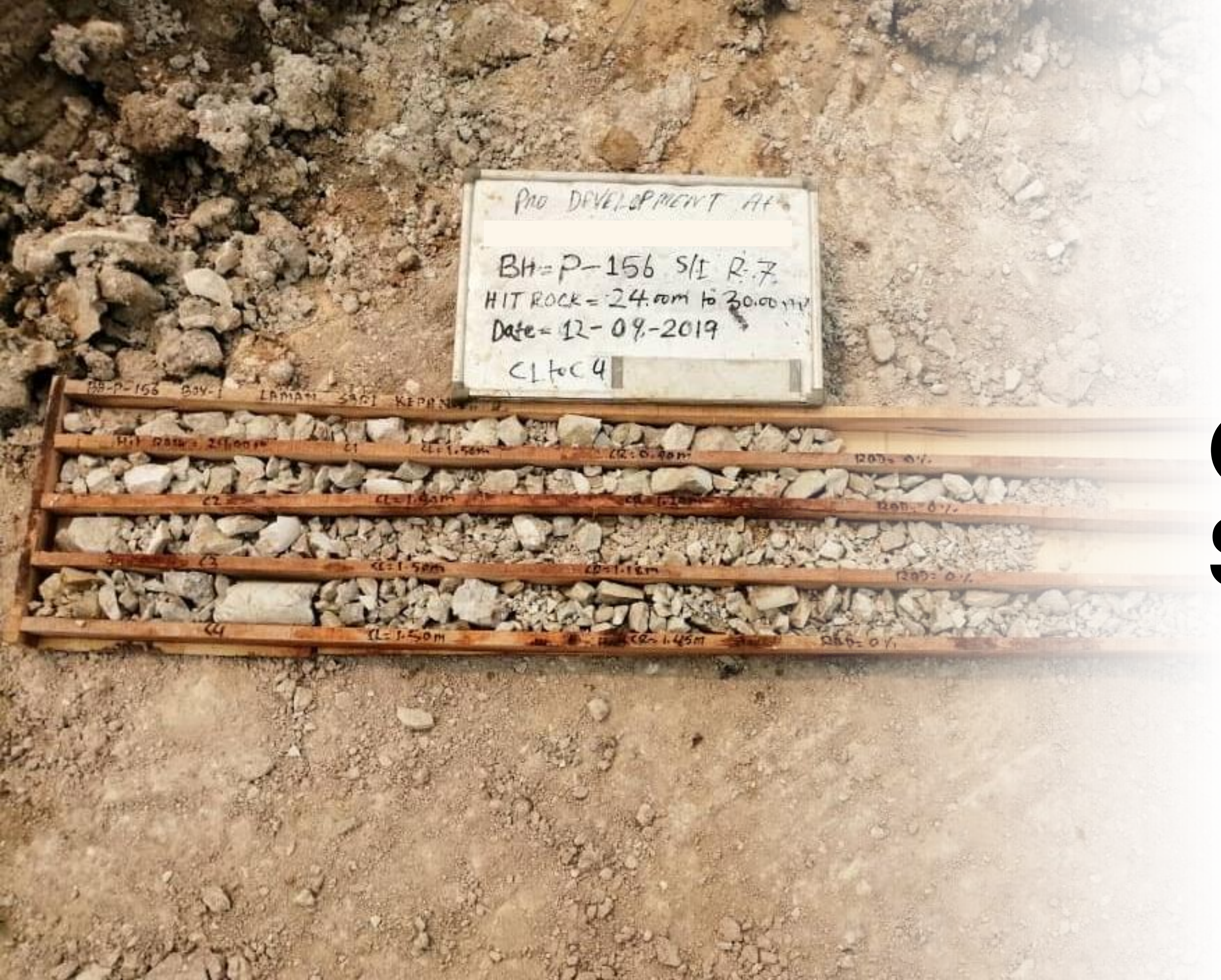

Case Study 3

Project Information

The high-rise residential condominium project is located in Batu Caves, Selangor.

The development consists of two 39-storey apartment blocks including an eight-level car park.

SI Scope

- 4 boreholes (BH) were proposed and conducted during the design stage.
- Consultant later proposed 91 additional borehole (ABH) to be carried out during construction stage.

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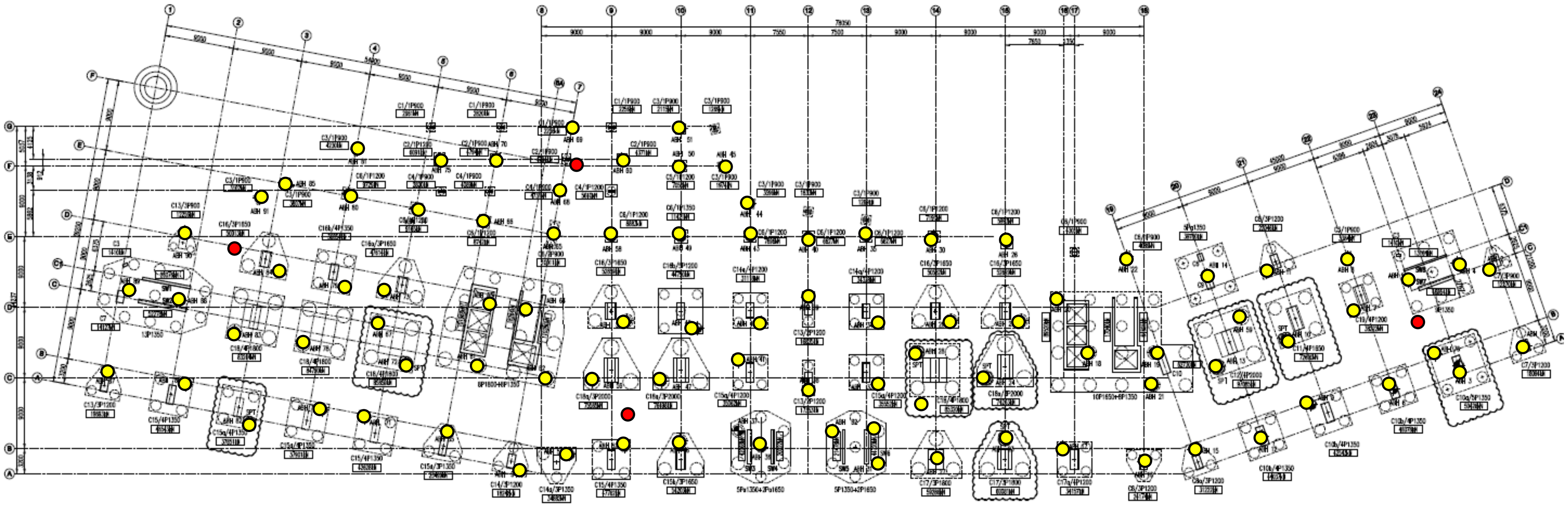
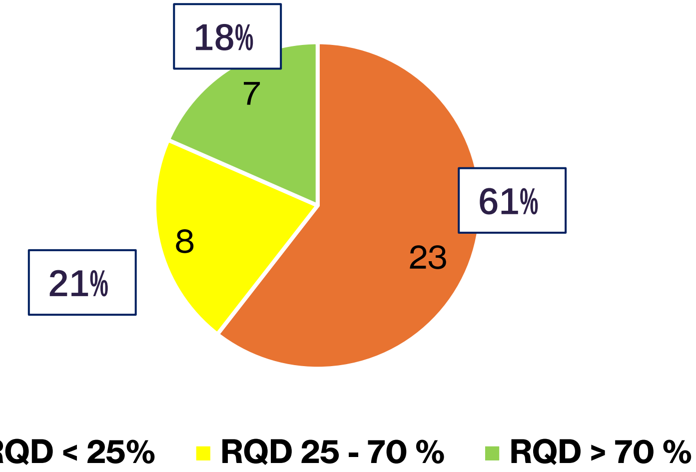


PILING LAYOUT

- Additional Borehole (ABH) conducted
- Initial Borehole (BH) conducted

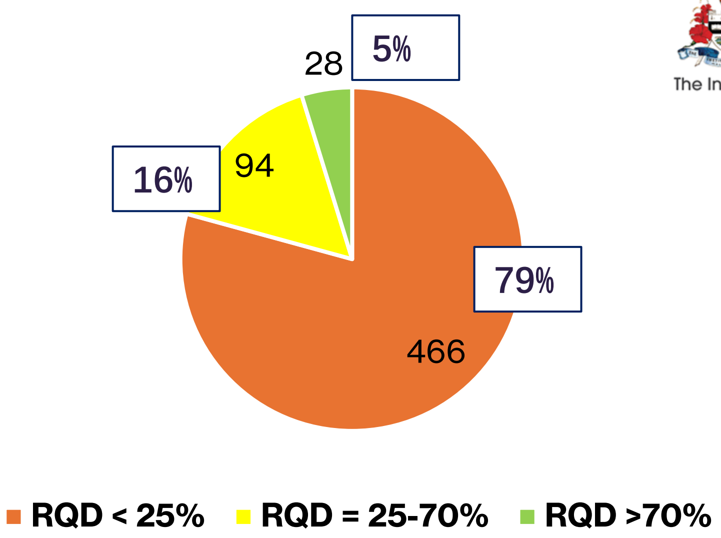
Rock Probing on Limestone

Interpretation



Initial 4 BH

- The total number of rock core samples from these 4 boreholes is 38.
- Based on SI report, the bedrock level ranges between 21m to 40m.



Additional 91 ABH

- The total number of rock core samples from these 91 additional boreholes is 588.
- Based on SI report, bedrock level ranges between 15m to 45 m.
- 6 nos. of ABH did not encounter any rocks until termination depth between 50m to 54m.

- The percentage of samples with RQD < 25% increased from 61% to 79%) in the additional boreholes. This suggests a higher proportion of poor-quality rock at the site.
- The percentage of high-quality rock samples dropped significantly from 18% to 5%. This suggests that good-quality bedrock is less prevalent in the expanded investigation area.
- The new data for bedrock level suggests a wider range in bedrock depth with a deeper maximum depth.
- The site may have more fractured, weaker rock than initially thought.

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Discussion

- Significant challenge to design pile foundation and estimate the cost based on 4 boreholes during design stage.
- A large number of additional boreholes were carried out after piling contract was awarded. The rock cores retrieved revealed a much higher percentage of very poor quality of limestone rock than initially expected.
- The revised design rock socket pile length exceeded the tender design upon preliminary test pile result which consistent with the findings from additional borehole results.
- Bored pile rigs at site used limited to 50m depth based on tender design. Rock socket level beyond 50m depth not possible without bringing in new rig.
- Numerous disputes between piling contractor and client/consultant mainly due to work delays and escalation of final costs .
- Probably carry out more boreholes during design stage rather than construction stage will provide more accurate data for design consultant to better evaluate the overall limestone rock quality and to determine required socket length.

What we learned from these case studies?

NOTE. The costs of a site investigation are low in relation to the overall cost of a project and can be further reduced or can improve project outcomes by intelligent forward planning. Discussion at all phases with a geotechnical adviser or appropriate specialist can be used to formulate an efficient and economic plan for the investigations.

NOTE. The imposition of limitations (for reasons of cost and time) on the amount of site investigation to be undertaken might result in insufficient information being obtained to enable the works to be designed, tendered for and constructed adequately, economically and on time. Additional investigations carried out at a later stage can prove more costly and result in delays.

The following "Notes" extracted from MS 2038: 2024 are very true.

SI Scope for Foundation on Limestone Formation

- All SI work shall follow Malaysian Standard "MS 2038 : 2024 Site Investigations - Code of Practice". For ground prone to dissolution such as limestone formation, further guidance is provided in Annex F of this MS 2038.

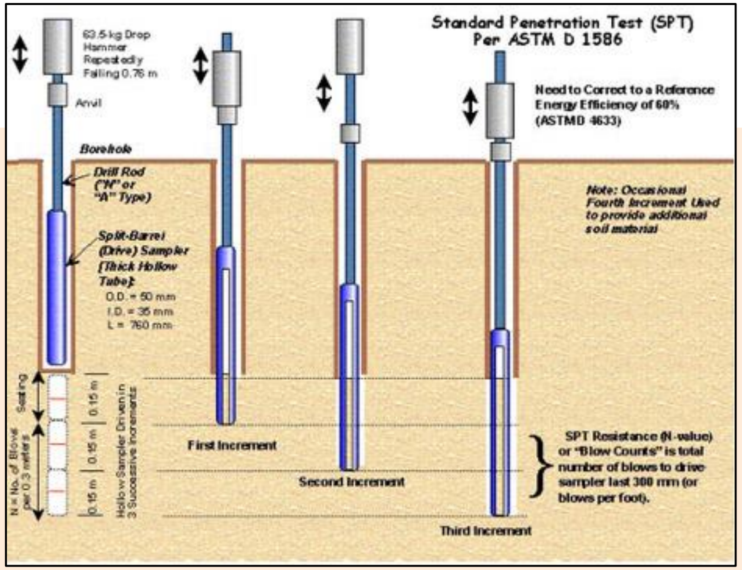
- Additional guideline, i.e. JKR's Garis Panduan Perancangan – Kerja Penyiasatan Tanah & Ujian Makmal (2019) can be referred. It provides recommendation for limestone formation.

- In general, more field & boring tests needed but less laboratory tests and undisturbed sampling is required in limestone formation.

- Geophysical survey methods can be conducted at site where erratic limestone bedrock is expected. Useful for interpolation between boreholes to detect any unpredictable voids or solution channels.

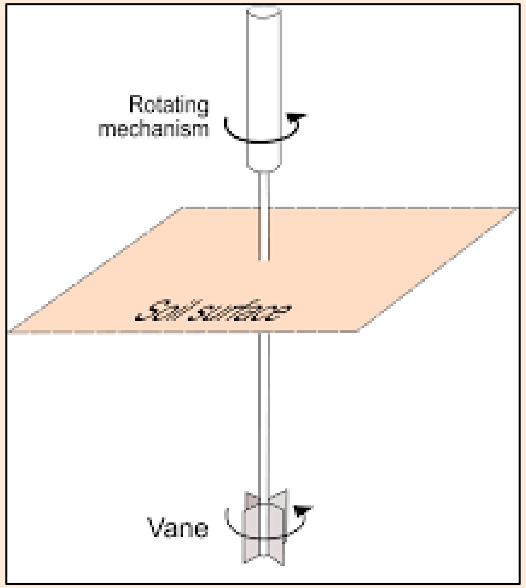
Insitu Tests

- Standard Penetration Test (SPT-N)
- Mackintosh Probe (MP)
- Cone Penetration Test (CPT)
- Vane Shear Test



Standard Penetration Test

Source :
[JKR] Garis Panduan Perancangan – Penyiasatan Tapak



Vane Shear Test

Source :
https://en.wikipedia.org/wiki/Shear_vane_test

Mackintosh Probe test

Source : https://www.linkedin.com/posts/mohammad-hafiz-504391155_mackintosh-probe-test-selalunya-digunakan-activity

Types of Sample

- Disturbed Sample
  - Split Spoon Sampler
- Undisturbed Sample
  - Thin Wall Sampler
  - Mazier Sampler

Split Spoon Sampler

Source : https://blog.certifiedmtp.com/split-spoon-sampler-how-it-works-in-soil-sampling/

Thin Wall Sampler

Source : [JKR] Garis Panduan Perancangan – Penyiasatan Tapak

Geophysical Test

- Seismic Refraction
- Microgravity
- 2D-ERI
- Ground Penetration Radar (GPR)
- MASW

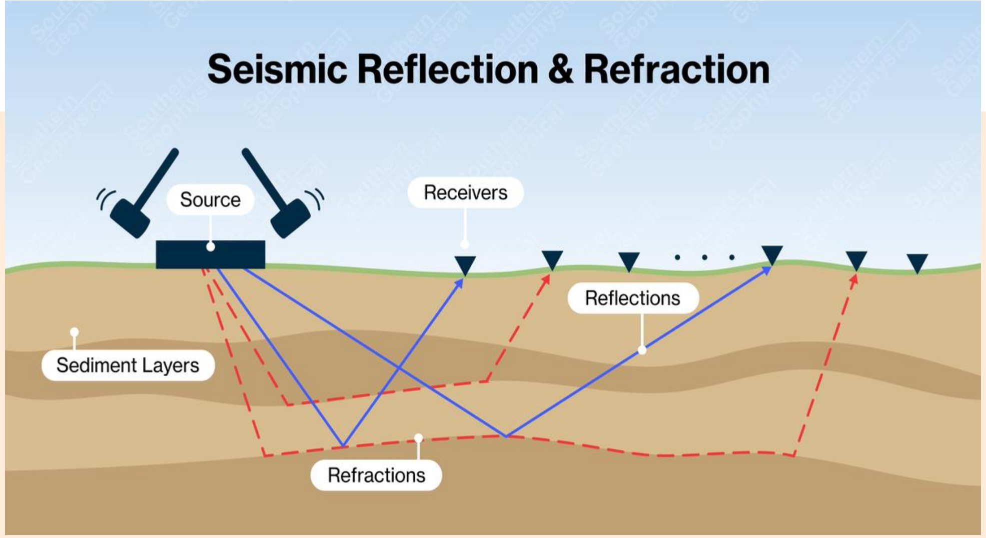


Illustration of Seismic Refraction

Source :
https://blog.certifiedmtp.com/split-spoon-sampler-how-it-works-in-soil-sampling/

The use of GPR Equipment at Site

Source : [JKR] Garis Panduan Perancangan – Penyiasatan Tapak

Laboratory Test

Classification Test

- Particle Size Distribution
- Moisture Content
- Atterberg Limit
- Dry Density Test
- Specific Gravity
- Bulk Density Test

Chemical Test

Soil Strength Test

- Triaxial Test UU/CIU/CD

Consolidation Test

Point Load Test (for rock sample)

Unconfined Compressive Strength, UCS (for rock sample)

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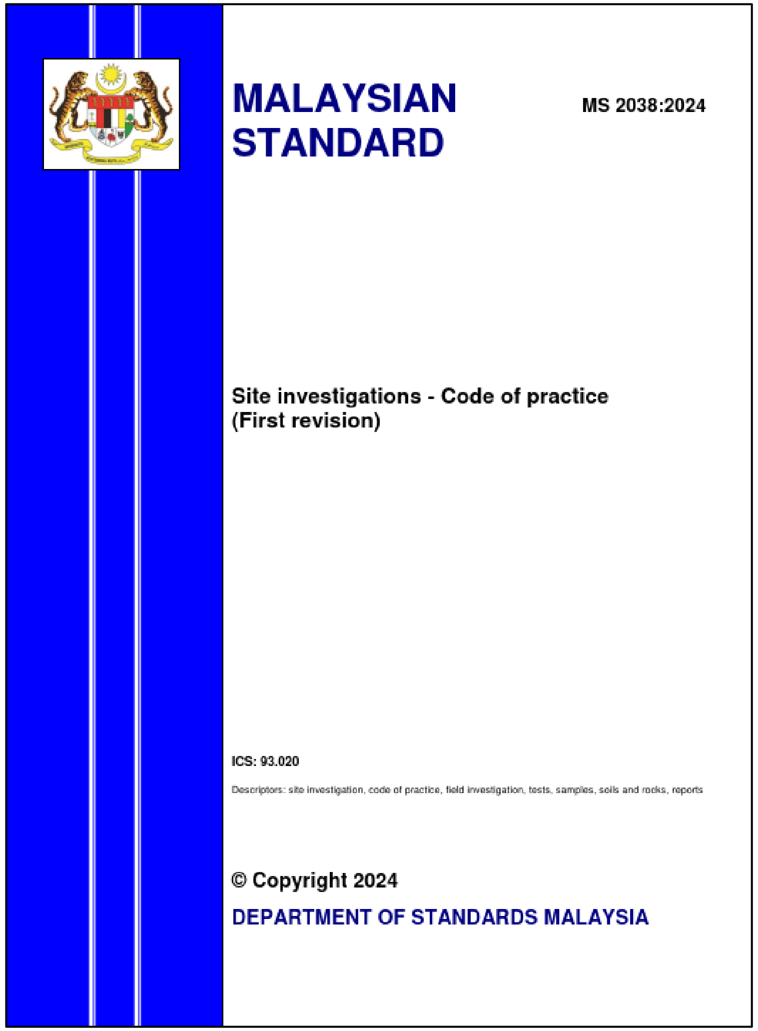
MS 2038 : 2024 *Site Investigations – Code of Practice (First Revision)* and JKR Guidelines (from *Garis Panduan Perancangan Kerja Penyiasatan Tanah 2019)*



Extracted from MS 2038 : 2024 and JKR Guidelines (2019)

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Criteria	MS 2038 : 2024	JKR Guidelines
Nos. of SI Points	<u>BUILDING (WITH MULTIPLE ADJACENT UNITS)</u> 1 investigation point per unit ***more investigation point needed for multi-story building** **Refer to MS 2038:2024 Clause 4.3.7.1** <u>BRIDGES</u> 2 to 6 investigation points per foundation **Refer to MS EN 1997-2:2015 Geotechnical Design and Testing-Clause B.3**	<u>BUILDING</u> • 2 BH for a block of low rise building on flatland. • For problematic and erratic soil formation like limestone areas, more boreholes are required (3-5 boreholes per block) • 2 lines resistivity **OR/AND** 5m spacing microgravity <u>BRIDGE (L<40m)</u> Minimum 2 BH for every abutment (opposite and crossed) <u>BRIDGE (L>40m)</u> 1 BH at every abutment and pier <u>OVERPASS (ONE SPAN)</u> 2 BH for every pier <u>OVERPASS (MULTIPLE SPANS)</u> 1 BH at every pier <u>VEHICULAR BOX CULVERT (VBC) (L<20m)</u> 2 BH (opposite & crossed) <u>VEHICULAR BOX CULVERT (VBC) (L>20m)</u> 3 BH (opposite & crossed)

Extracted from MS 2038 : 2024 and JKR Guidelines (2019)

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Criteria	MS 2038 : 2024	JKR Guidelines
Borehole Spacing	<u>FOR HIGH RISE AND INDUSTRIAL STRUCTURES</u> Grid pattern with points at **15m - 40m distance** <u>FOR LARGE-AREA STRUCTURES</u> Grid pattern with points **not more than 60m distance** <u>FOR LINEAR STRUCTURES (CHANNELS, PIPELINES TUNNELS, RETAINING WALL)</u> Spacing of **20m - 200m** **All the above refer to MS EN 1997-2:2015 Geotechnical Design and Testing-Clause B.3**	<u>BUILDING</u> For multistory building, spacing **between 15m to 45m** (depending on the uniformity of strata, geological conditions and foundation type) <u>BRIDGE</u> Distance between boreholes **minimum 20m**

Extracted from MS 2038 : 2024 and JKR Guidelines (2019)

Criteria	MS 2038 : 2024	JKR Guidelines
Termination Depth	<u>HIGH RISE STRUCTURES AND CIVIL ENGINEERING PROJECTS</u> • > 6m **OR*** (3 x smaller side length of foundation) **Refer to MS EN 1997-2:2015 Geotechnical Design and Testing-Clause B.3** • Termination depth must cover all significantly stressed ground <u>PILES</u> Pile length + 5.0m OR* Pile length + foundation width OR* Pile length + (3 x pile base diameter) *whichever largest **Refer to MS EN 1997-2:2015 Geotechnical Design and Testing-Clause B.3**	<u>BUILDING</u> 5 times SPT-N > 50 **OR*** 45m termination depth <u>BRIDGE</u> 7 times SPT-N> 50 **OR*** 50m termination depth <u>FOR AREA WITH LIMESTONE FORMATION</u> • **Limestone R/r>50% AND No Cavity** 6.0m • **Limestone R/r<50% OR With Cavity** 9-21m *whichever comes first

Additional Guidelines

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Criteria	BS 5930:1999 Code of Practice for Site Investigations
Borehole Spacing	<u>BUILDING STRUCTURES</u> Relatively close spacing **between 10m to 30m** (depending on the uniformity of strata, geological conditions and foundation type)
Nos. of SI Points	<u>STRUCTURES (IN SMALL PLAN AREA)</u> **Minimum 3 points** (unless other reliable information in available in the immediate vicinity)

Additional Guidelines

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Criteria	ICE Specification for Piling and Embedded Retaining Walls 2nd Edition 2007 – Part A
Depth of Termination	**PILES** The minimum depth should be as deep as the deepest pile.
Nos. of SI Points	**PILES** Requires several explorations points (BS 5930 requires minimum 3 points)

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How To Ensure Sufficient Data in Limestone for Pile Design & Construction

1. **Experience supervisor or geologist to supervise the work** full-time at site.

2. Propose **additional boreholes or geophysical survey** at location where **anomalies** are encountered.

3. **Rock probing** (without field testing) to determine rock head level, rock quality and the presence of karstic features.

Issues During SI Work

- **Core Barrel Rod Drops into Void Cavity**

The presence of large cavities or voids can cause the core barrel tip to drop unexpectedly into these openings resulting in delays in the investigation.

- **No Water Return**

Water used to facilitate drilling may seep into voids or cavities, leading to a loss of water return at the surface.

- **Ground Depression or Subsidence**

The collapse of cavities or voids in limestone bedrock during borehole drilling leads to ground depression or subsidence at the surface.

Ground Depression

Engineer’s Responsibility for SI Work

1. **PLAN by Submitting Person - PEPC**

   To plan the SI work after reviewing all available information of the site

2. **WORK - Qualified and Experienced Personnel**

   To conduct SI according to approved methods

3. **SUPERVISION - Professional engineer who is responsible for design or qualified person under his control**

   To supervise the SI work to ensure its compliance with standards

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Rev. No.: 1
Date: 25.5.2017

BOARD OF ENGINEERS MALAYSIA

CIRCULAR NO. 006

ENGINEER’S RESPONSIBILITY FOR SUBSURFACE INVESTIGATION
(Generally also known as soil investigation)

In exercise of the powers conferred by paragraph 4(1)*(f)* of the Registration of Engineers Act 1967 [*Act 138*], the Board of Engineers Malaysia hereby determines as follows:

1. Subsurface Investigation (S.I.) shall be planned by the Submitting Person after a desk study and site reconnaissance, including reviewing of all available information of the site and adjacent areas. The methods of subsurface investigation and sampling for laboratory tests must also be adequately specified and be relevant to the geological and the ground conditions. Guidelines can be obtained from MS 2038 Code of Practice for Site Investigation and MS 1056 Method of Test for Soils for Civil Engineering Purposes.
2. S.I. shall be carried out by qualified and experienced personnel according to approved methods.
3. S.I. shall be supervised by the professional engineer who is responsible for the design or by qualified person under his control.

[326th Board Meeting / 25th May 2017]

DATO’ SRI Ir. Dr. ROSLAN BIN MD. TAHA
President

Board of Engineers Malaysia (BEM) Circular No. 006 Dated 25th May 2017

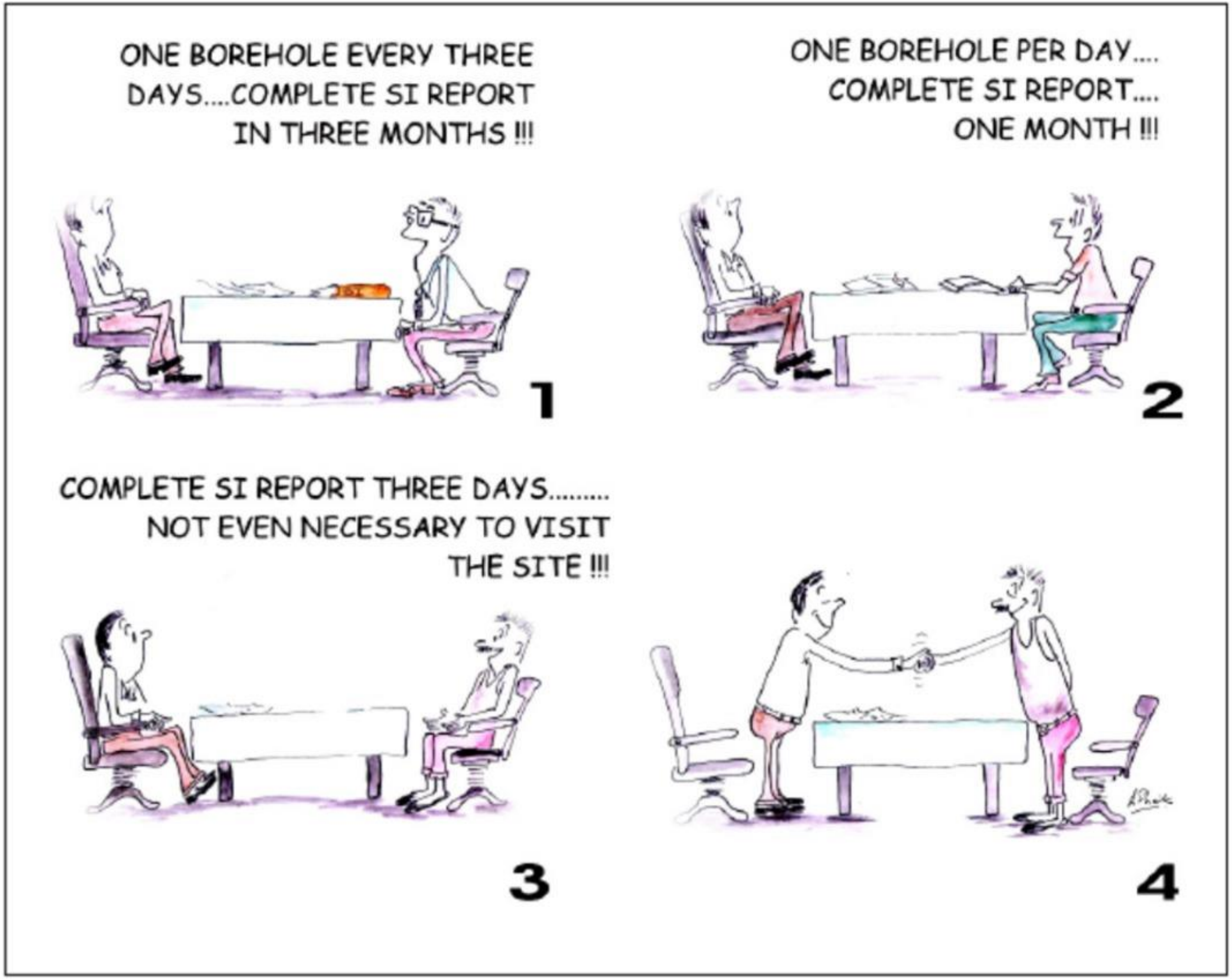
Problems of Deficiencies SI Data

- the most basic of information was frequently missing
- 20% of piling contracts had no borehole data
- in nearly 60% of cases there was inadequate topographical information
- rarely was a proper geotechnical desk study undertaken
- in more than half of the projects surveyed, environmental concerns dominated the investigation at the expense of the geotechnical element, which was often compromised or absent
- information freely available was often not passed to the contractor (in 17% of contracts, borehole location plans were not provided, rendering useless any borehole information).

these deficiencies commonly result in the following.

- The piling contractor adding more 'risk money' to their price to cover their risk (more than an adequate investigation would have cost in the first place).
- Delay costs arising out of unforeseen conditions.
- Construction and legal costs arising from unforeseen ground conditions.

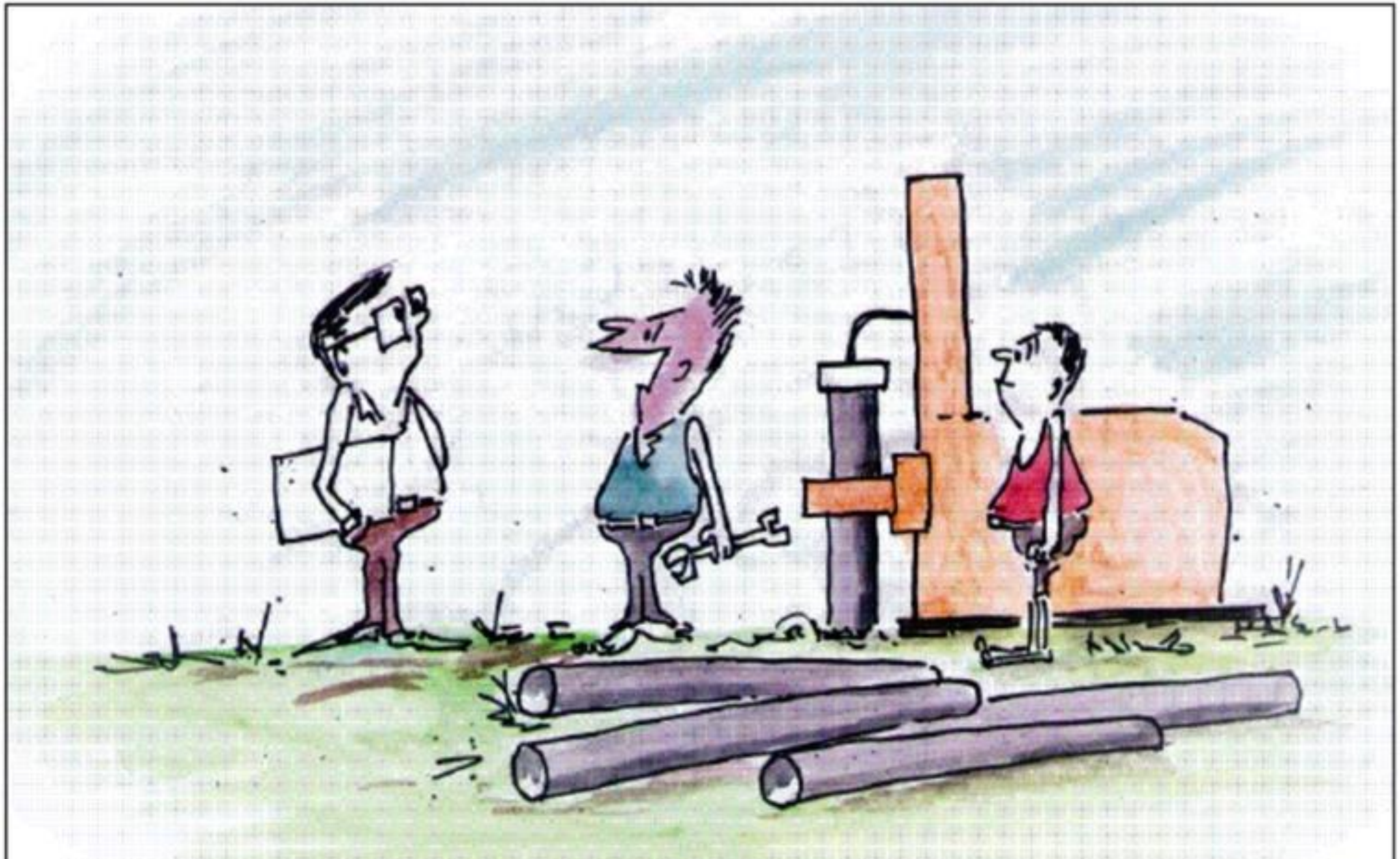
Source: Clayton, C.R.I & Smith, D.M. (2013). *Effective Site Investigation.* ICE Publishing.



IEM
The Institution of Engineers, Malaysia

Source:
A.W.Shaik,
Toward More Reliable Site Investigation Information

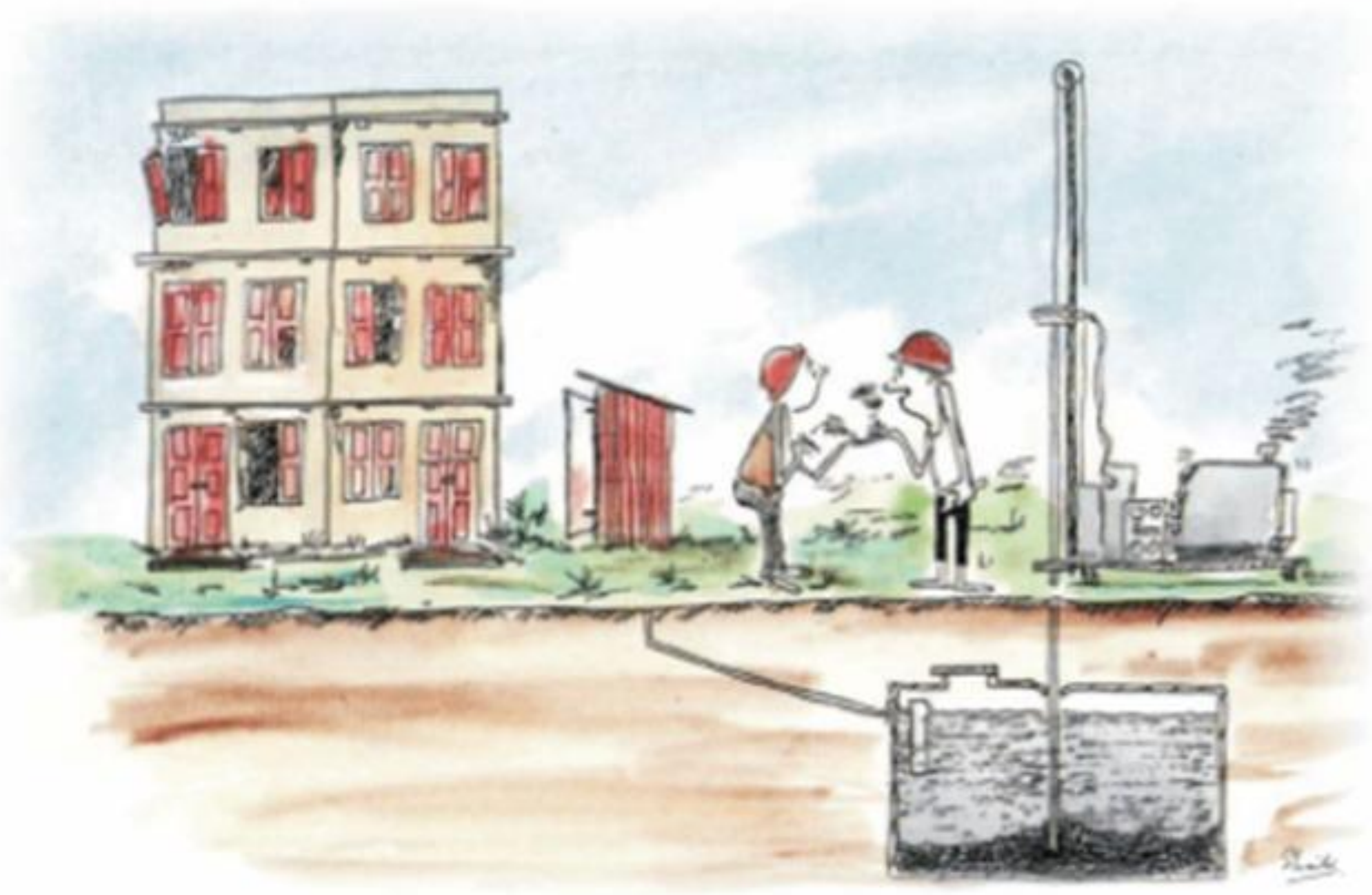
IEM
The Institution of Engineers, Malaysia



"..WHY DO WE NEED MORE EQUIPMENT ?...WE JUST DO THE BOREHOLES HERE...... ALL OTHER FIELD TESTS AND SAMPLINGS ARE DONE IN THE OFFICE..!!!"

Source:
A.W.Shaik,
Toward More Reliable Site Investigation Information

Sample logging is a serious business...



"...SOFT, DARK BROWN WITH MUCH AMORPHOUS ORGANIC MATTER AND PECULIAR ORGANIC TYPE SMELL...!!!"

Source:
A.W. Shaik,
The Engineer

Conclusion

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1. Planning and execution of proper site investigation by **an experienced design engineer with geotechnical knowledge and good understandings in limestone formation** is very important. Without a properly procured, supervised and interpreted site investigation, hazards which lie in the ground beneath the site cannot be known.

2. **Inadequate site investigations** can arise from a **lack of awareness** of the importance of ground, **amount of finance**, **insufficient time** and **lack of geotechnical expertise.**

3. These shortcomings result in **additional delays and costs**, which are often more than the original price of SI.

4. It is **important to conduct sufficient SI before the construction of a project.** Skipping or lack of SI can likely cause unexpected problems later, which end up being more expensive than the initial cost.

5. In summary, **Without (or even poor planning) Site Investigation, Ground is a Hazard!** This is very true especially for proposed development in Limestone formation.

Limestone Sinkhole at Mount Gambier, Australia

THANK YOU

KEEP EXPLORING AND LEARNING !

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